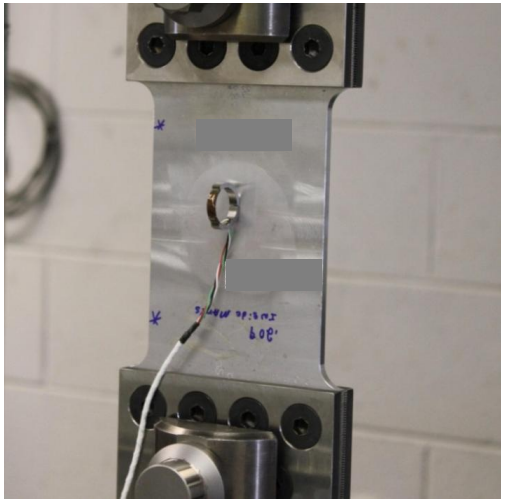
Damage Tolerance Assessment of Friction Pull Plug Welds in Two Aluminum Alloy Systems

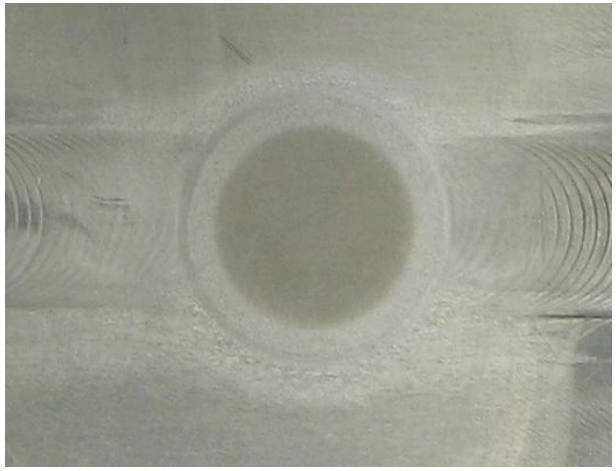
Preston McGill
Jonathan Burkholder

Materials and Processes Laboratory
NASA Marshall Space Flight Center



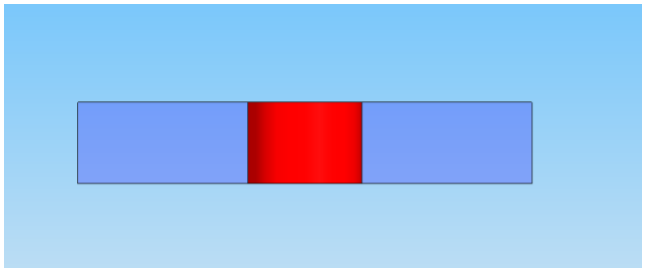
NASA Human Space Flight Requirements

NASA safety requirements call for fault tolerance or a minimum risk approach for manned flight hardware. Fracture control is one element of a minimum risk approach. The basic philosophy behind fracture control is mitigating risk associated with a part failing from a crack or crack-like defect.

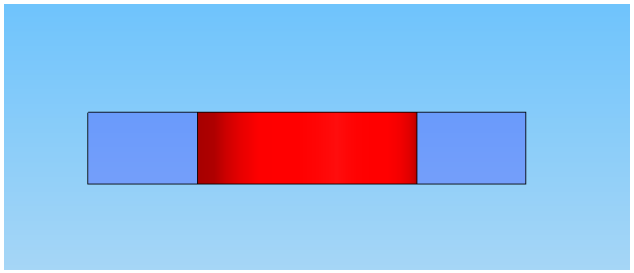


Plug welds pose a unique challenge to fracture assessment because standard fracture test methods can't be easily applied

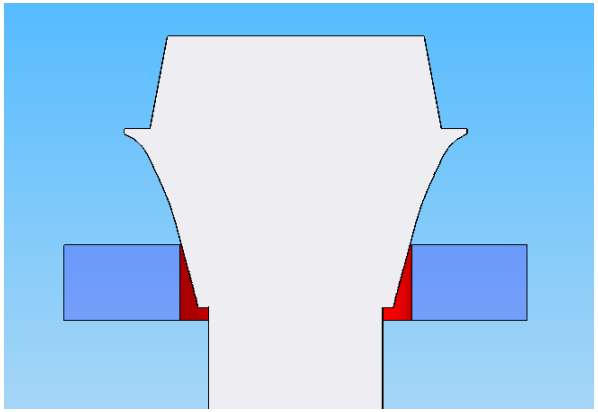
- A plug weld is a non-homogenous anisotropic material system
- Local deformation and failure behavior not initially understood
- Pre-crack placement is non-straightforward



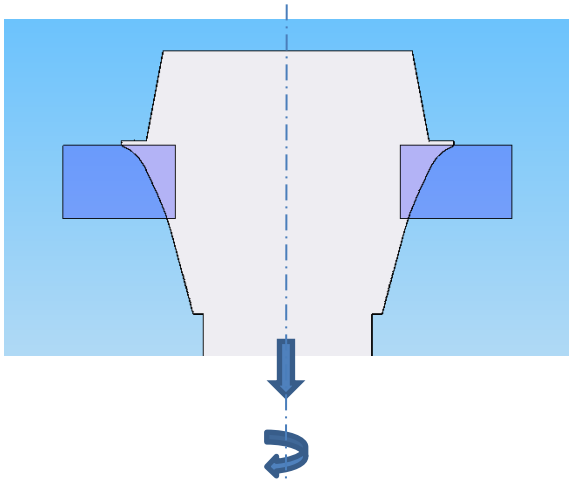
Self-reacting Friction Stir Weld Termination Hole



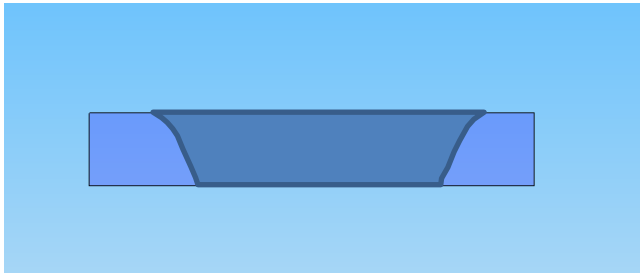
Hole Enlarged to Accommodate Pull Plug



Pull Plug at “zero” Displacement



Pull Plug at “full” Displacement



Pull Plug after Final Machining

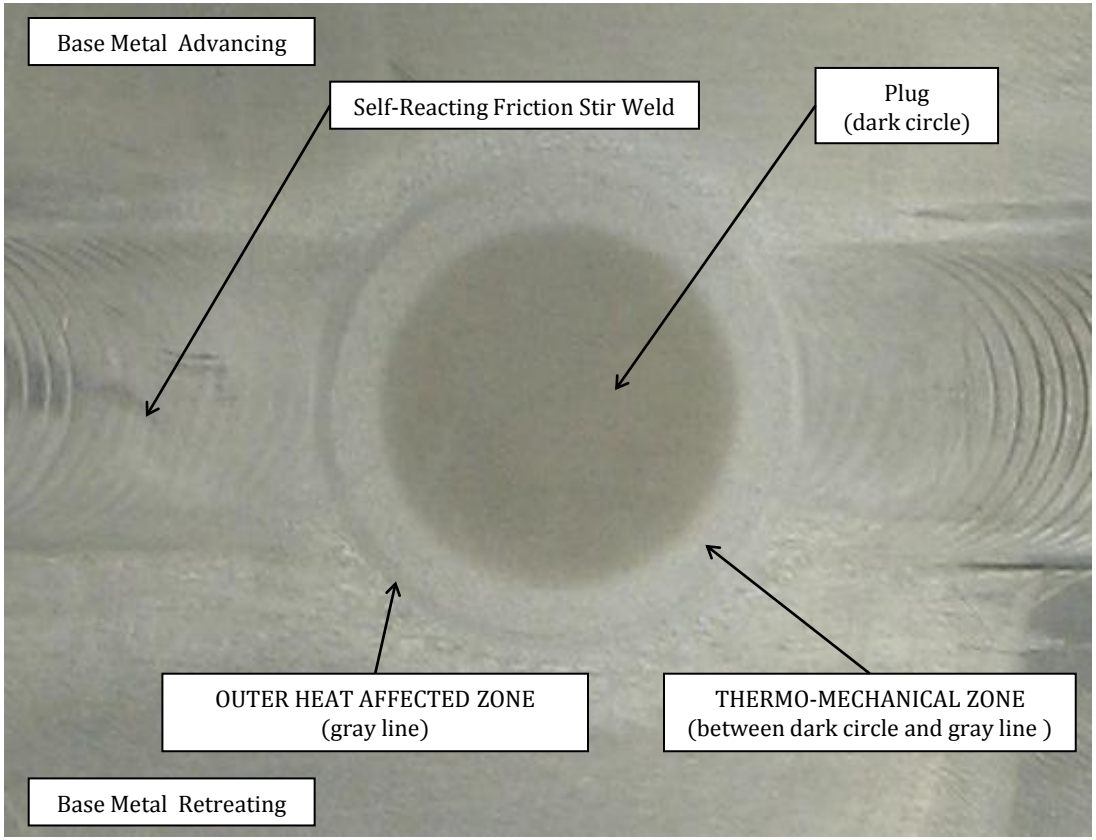
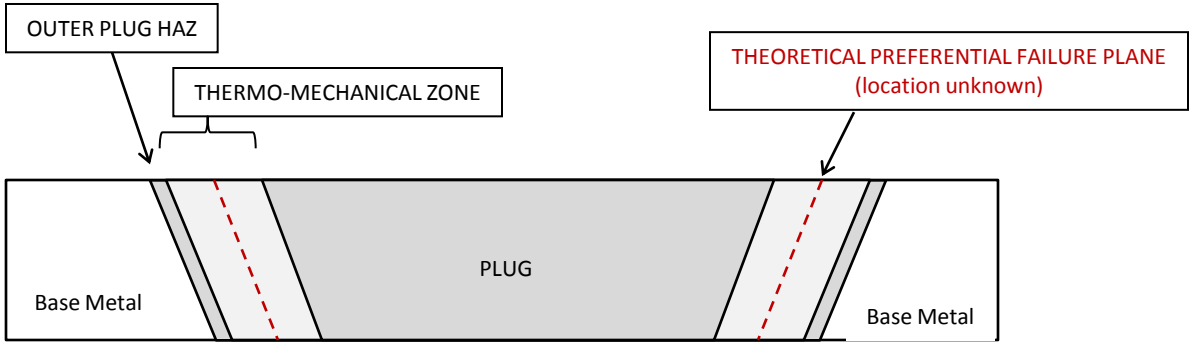
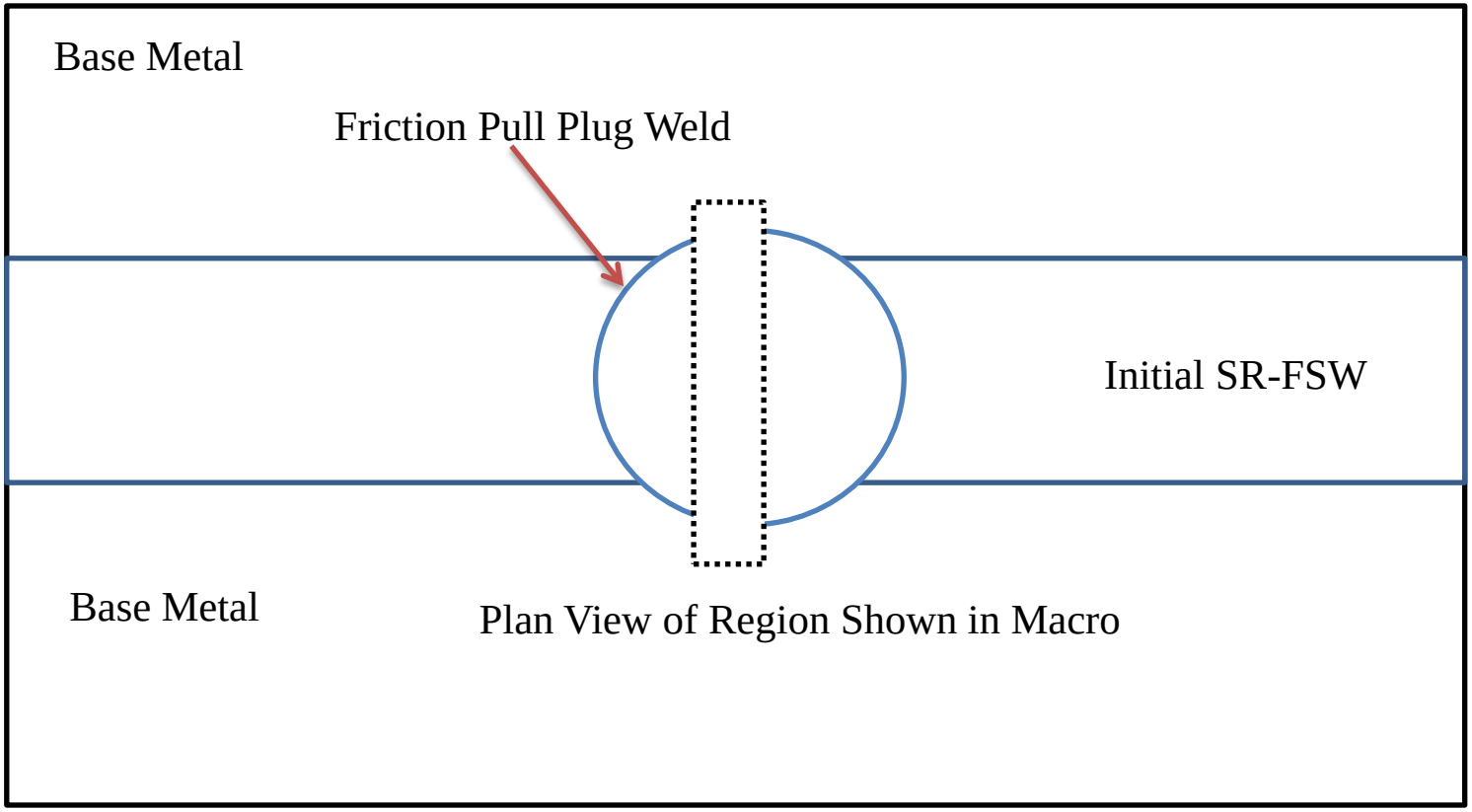


Image of plug weld illustrating complexity of plug-plate interface. The preferential failure plane lies somewhere in the thermo-mechanical zone.



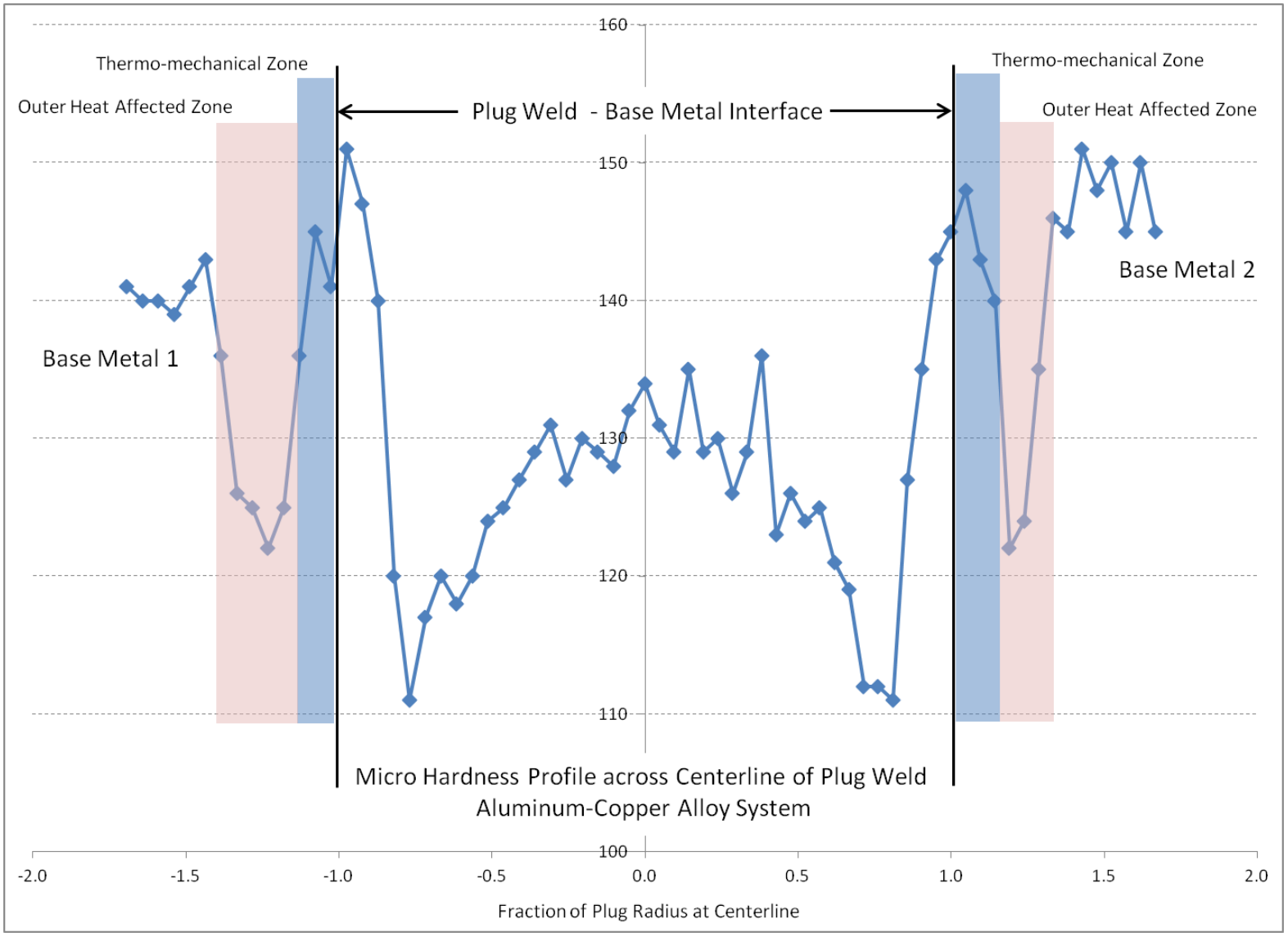


Partial Plan View of Friction Plug Weld

Cross Section of Friction Plug Weld

Cross Section of Friction Plug Weld
- Interface at Base Metal

Cross Section of Friction Plug Weld
- Interface at Initial Weld


Thermo-mechanical Zone
Outer Heat Affected Zone
Plug Weld - Base Metal Interface
Thermo-mechanical Zone
Outer Heat Affected Zone
Base Metal 1
Base Metal 2
160
150
140
130
120
110
100
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
Micro Hardness Profile across Centerline of Plug Weld
Aluminum-Copper Alloy System
Fraction of Plug Radius at Centerline

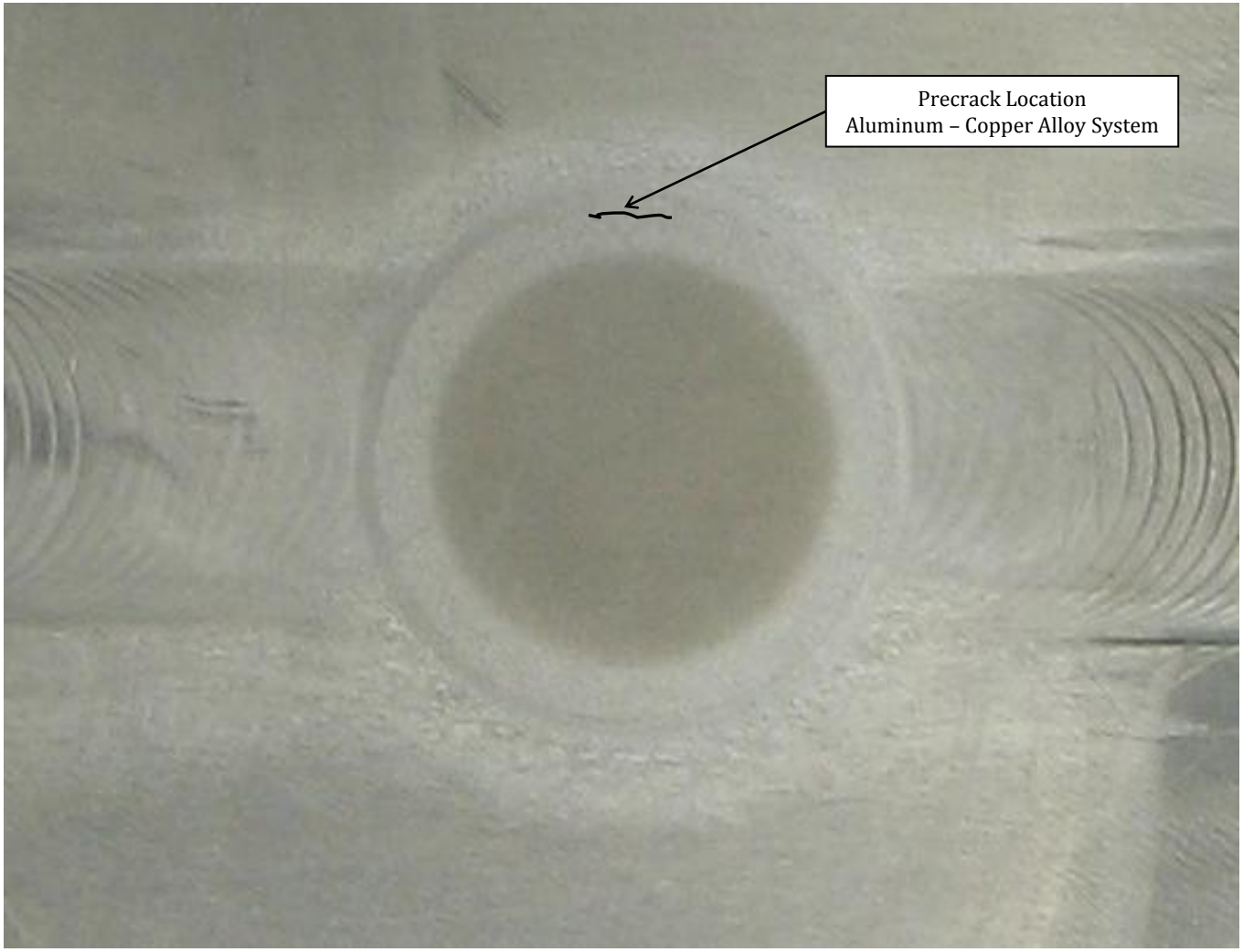


Image of plug weld illustrating precrack location.

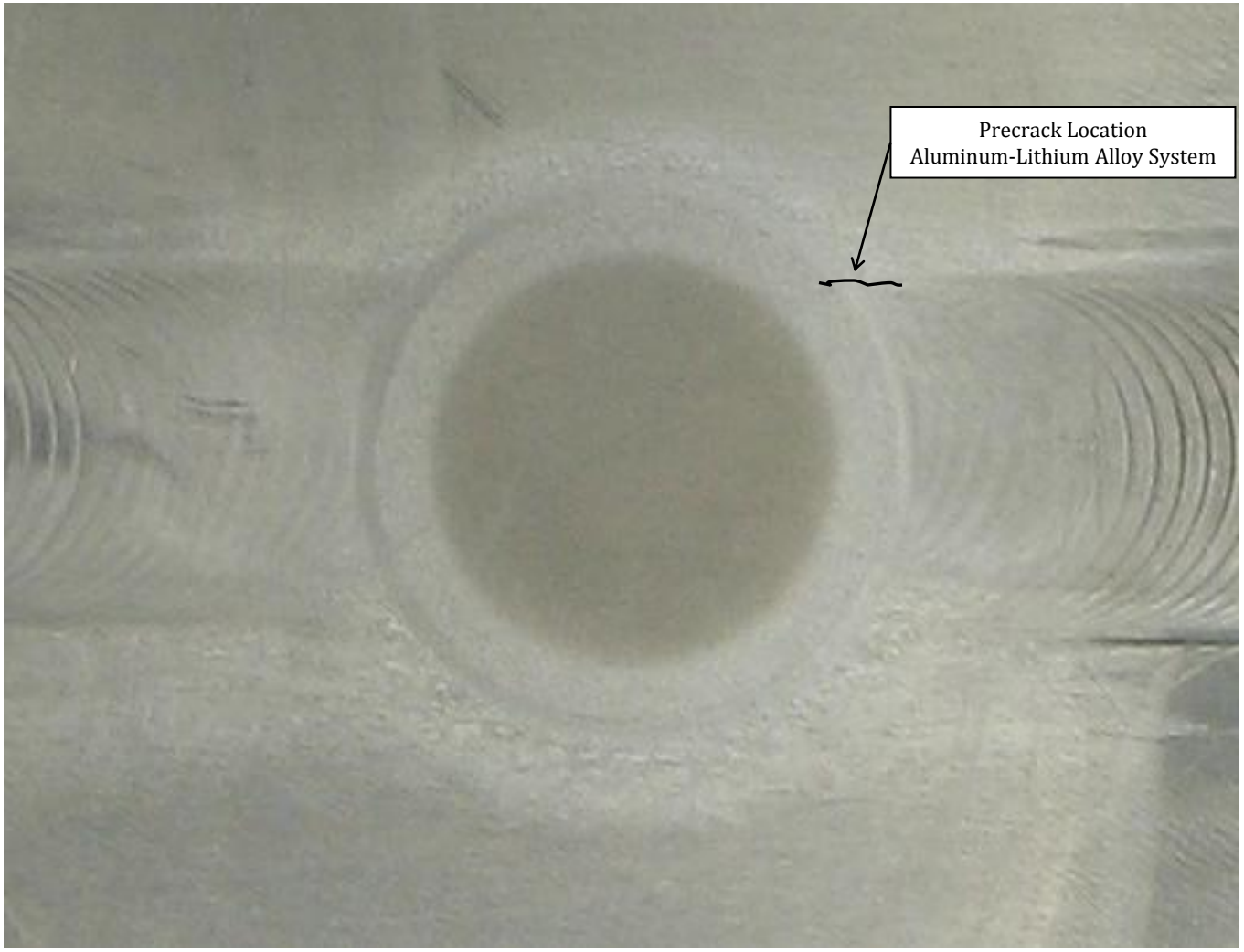
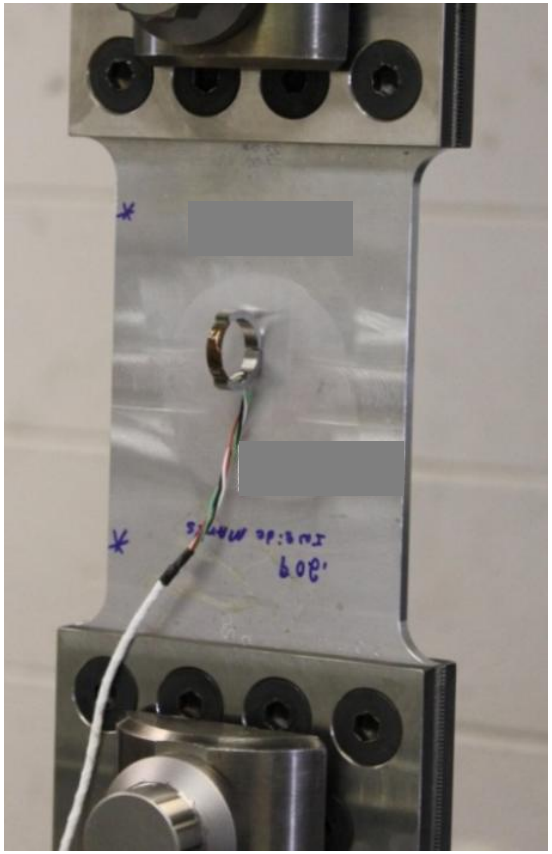
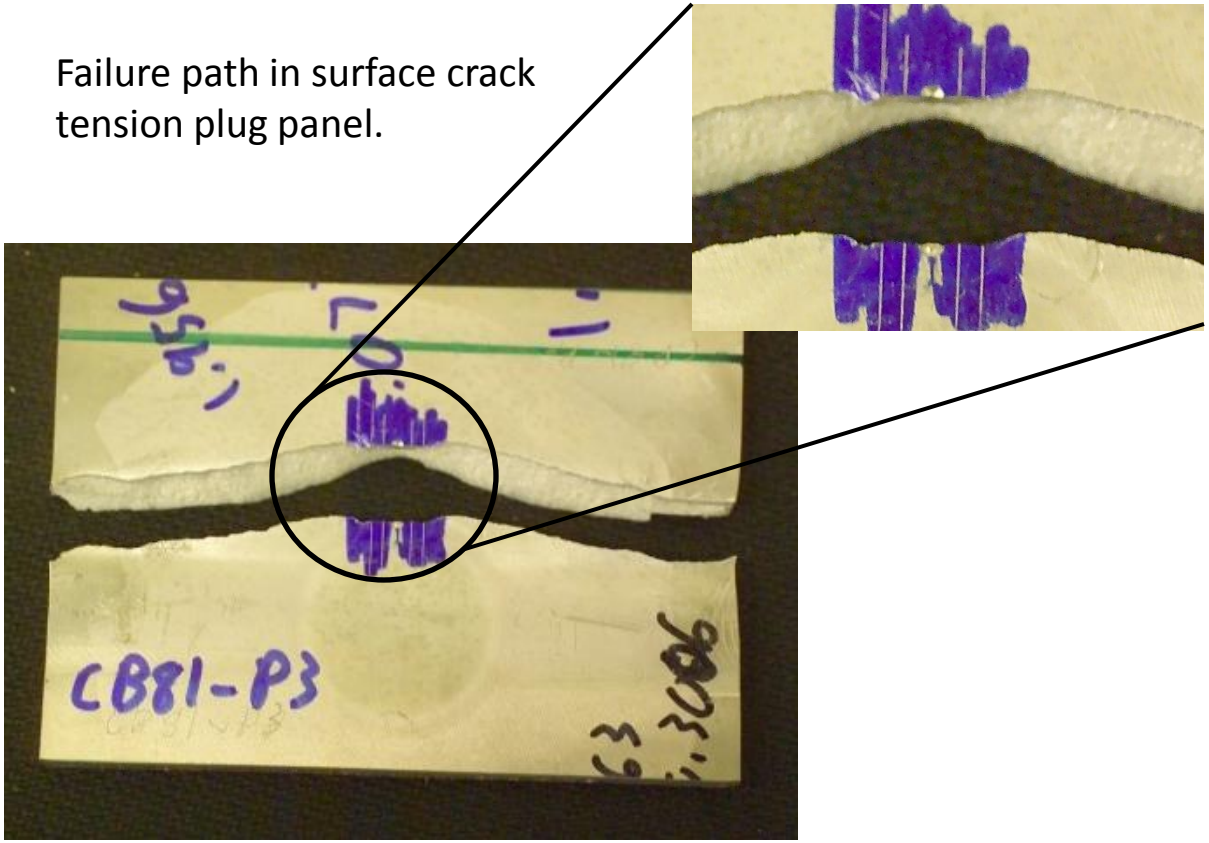


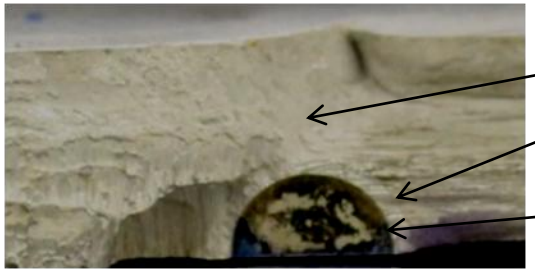
Image of plug weld illustrating precrack location.

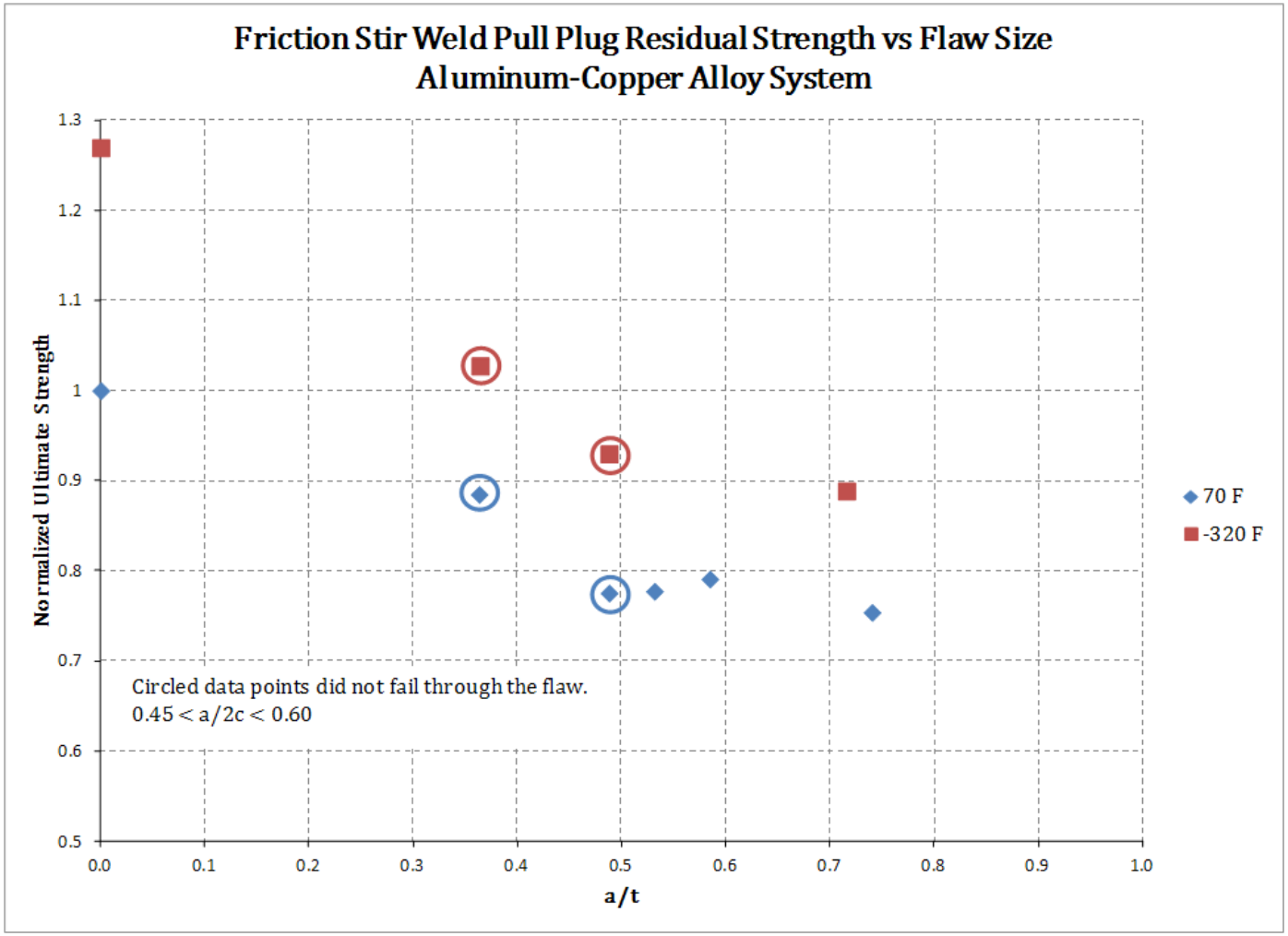


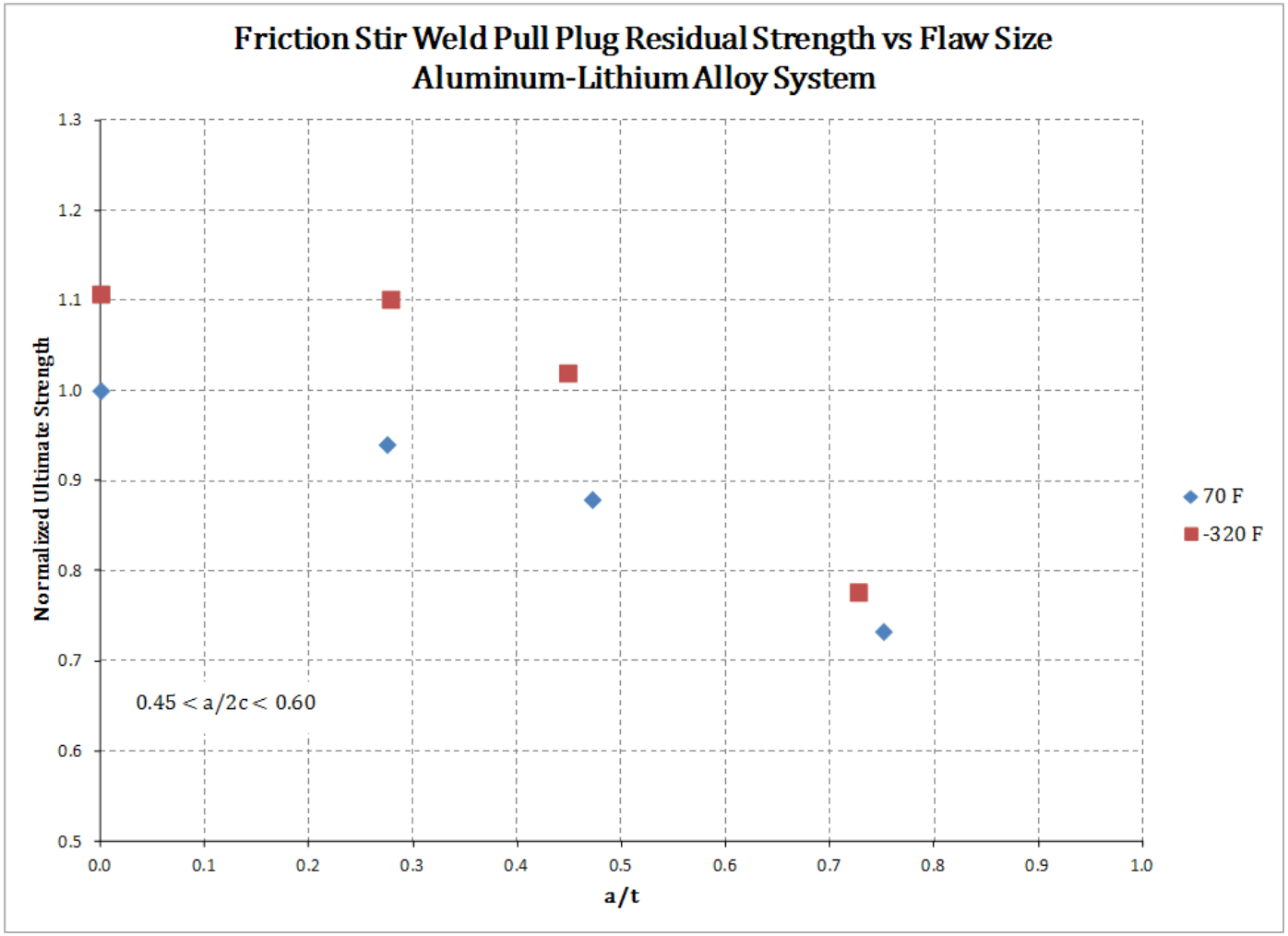
Failure path in surface crack tension plug panel.



Friction Plug Weld Surface Crack Tension Test Sample




Friction Stir Weld Pull Plug Residual Strength vs Flaw Size
Aluminum-Copper Alloy System
Normalized Ultimate Strength
a/t
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Circled data points did not fail through the flaw.
0.45 < a/2c < 0.60
70 F
-320 F


Friction Stir Weld Pull Plug Residual Strength vs Flaw Size
Aluminum-Lithium Alloy System
Normalized Ultimate Strength
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
a/t
0.45 < a/2c < 0.60
70 F
-320 F

- Residual strength of aluminum-copper alloy plug systems exhibits a cryogenic strength enhancement that is fairly constant with respect to flaw size.
- Residual strength of aluminum-lithium alloy plug system exhibits a cryogenic residual strength enhancement that decreases with flaw size and reaches a cross-over point at an a/t ratio of approximately 0.75.

Estimated Critical Flaw Depths			
	Temperature	70°	-320°
Alloy System			
Aluminum-Copper		0.75 t	0.50 t
Aluminum-Lithium		0.75 t	0.70 t

- Critical surface flaws can be reliably detected with liquid penetrant nondestructive evaluation.
- With respect to proof testing as a screen for mission critical defects, aluminum-lithium alloy weld systems may require a higher proof test factor than aluminum-copper alloy weld systems.